



# Thermochemistry

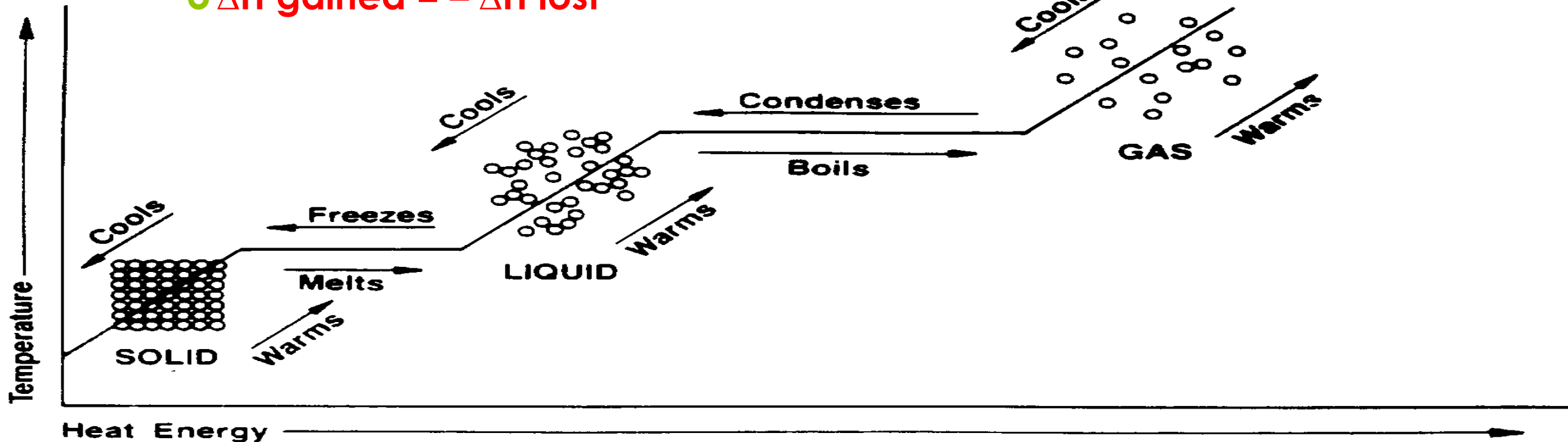
Chapter 17

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# Thermochemistry

- The study of energy changes that occur during chemical reactions and changes in state.
- The amount of heat gained/lost by the system must equal that gained/lost by the surroundings according to the **Law of Conservation of Energy**.

•  $\Delta H \text{ gained} = - \Delta H \text{ lost}$



# Energy

- The ability to do work.
- It can take many forms:
  - Electrical Energy
  - Potential Energy
  - Mechanical Energy
  - Thermal Energy
- We're going to focus on the last one, which is also known as **heat**.

# Heat Energy?

- Heat is **not** the same as temperature.
- **Temperature** is a measure of the average kinetic energy of molecules.
- **Heat** is a measure of thermal energy; how much energy something has.

## Heat Energy *cont.*

- There is no such thing as “cold.”
- In chemistry, there is only heat and the absence of heat. Cold does not exist.
  - If something feels cold, it simply means it has less heat (less energy) in its particles.
  - So when you think about it, your freezer is just a low-energy zone.

# Heat

- In chemistry, heat is represented with two different symbols:
  - $q$  (lowercase Q)
  - $\Delta H$  (meaning “change in heat”)
    - $\Delta H$  is also called **enthalpy**, which is the amount of heat in a system.
- **Important: The heat transfer continues until both reach the same temperature.**

# Measuring Heat

- Chemists measure heat in either of the following ways:
  - joules (J)
  - calories (cal)
- NOT in temperature scales.

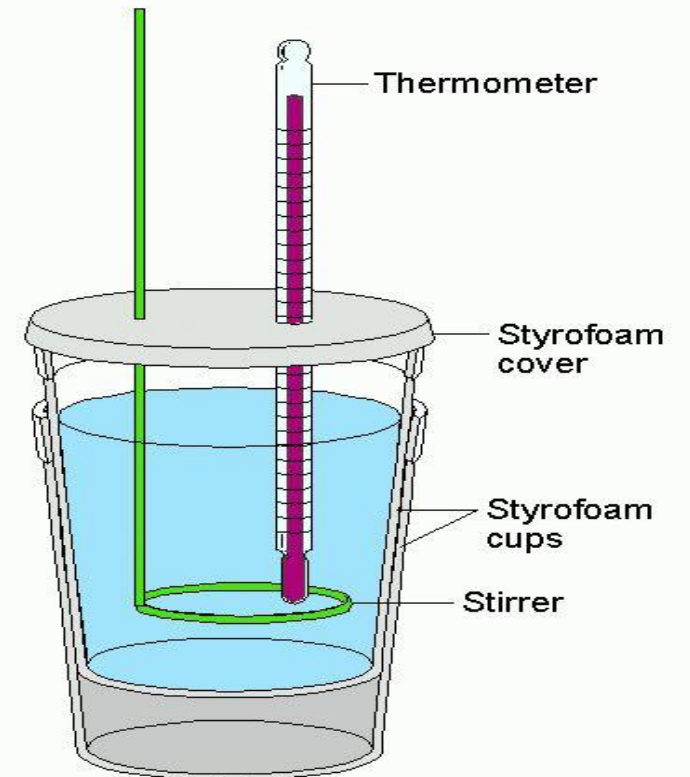
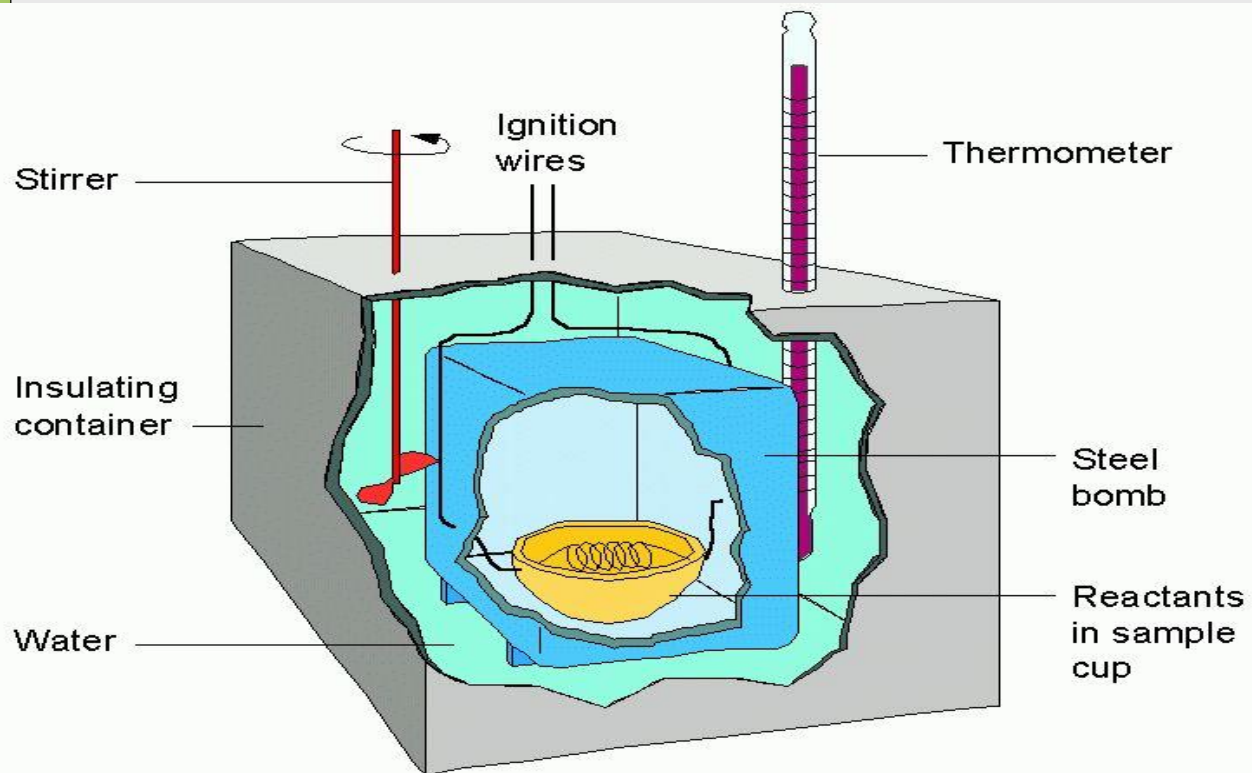
# calories and Calories

- A **calorie** (small c) is the amount of energy needed to raise the temperature of 1 g (1 mL) of water by 1 °C.
- A **Calorie** (big C) is 1000 calories.
  - Calories are also called **kilocalories** (**kcal**).
  - The amount of energy needed to raise 1 kg by 1 °C.



# Calorimetry

- Chemists can measure the enthalpy change of a reaction using a **calorimeter**.



# Joule and calorie Conversions

- **IMPORTANT:**

- $1 \text{ cal} = 4.184 \text{ J}$

- $1 \text{ kJ (kilojoule)} = 1000 \text{ J}$

- $1 \text{ kcal (kilocalorie)} = 1000 \text{ cal} = 1 \text{ Cal}$

- Only food chemists use Calories.

- Chemists in general use kilocalories to avoid confusion.

# Joule and calorie Conversions

- How many calories are in 100.0 J?
  - 1 cal = 4.184 J
  
- How many joules are in 522 calories?
  - 1 cal = 4.184 J

# Demonstrations

- $\text{NH}_4\text{NO}_3 (s) \rightarrow \text{NH}_4^+ (aq) + \text{NO}_3^- (aq)$ 
  - What do you feel?
  - Endothermic Reaction
  
- $\text{NaOH} (s) \rightarrow \text{Na}^+ (aq) + \text{OH}^- (aq)$ 
  - What do you feel?
  - Exothermic Reaction

# Reaction Types

- **ENDOTHERMIC**

- Heat enters the system
- “Feels Cold”
- Heat is a Reactant
- $+\Delta H$

- **EXOTHERMIC**

- Heat exits the system
- “Feels Hot”
- Heat is a product
- $-\Delta H$

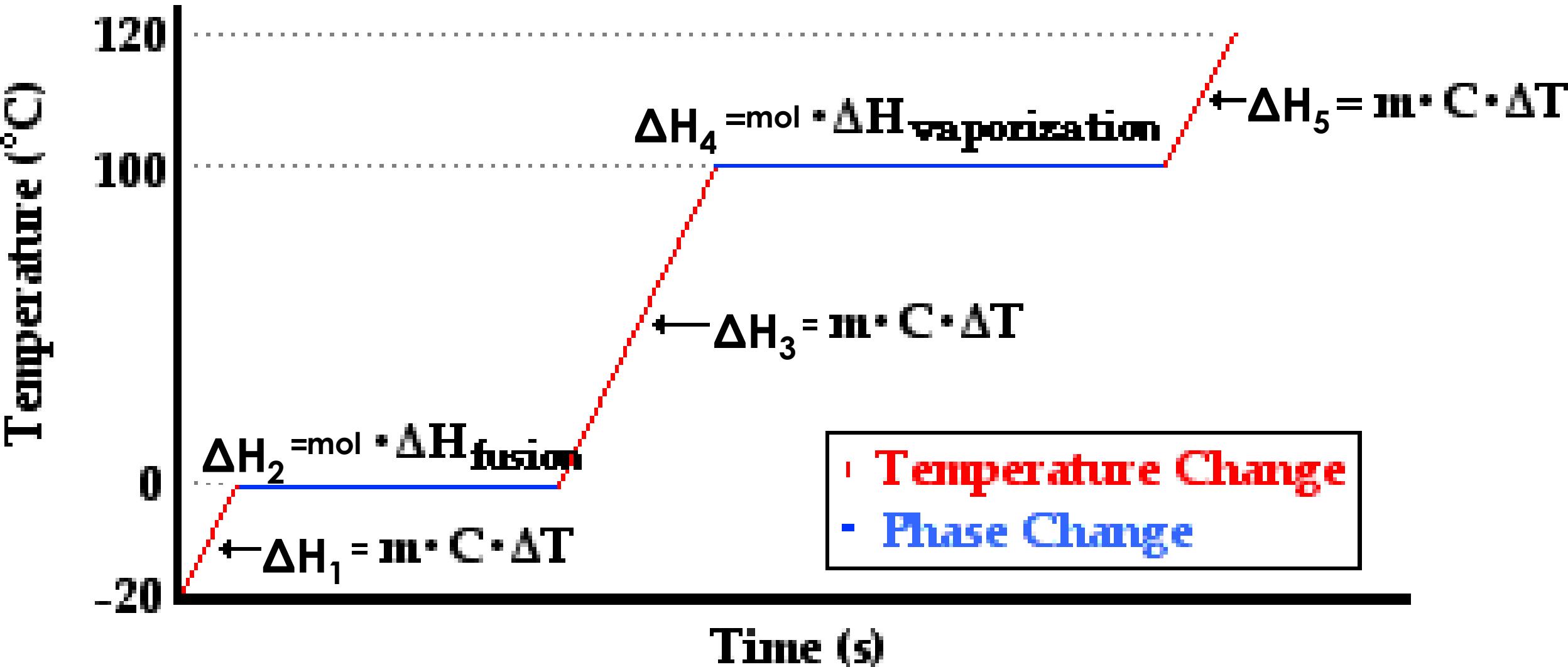
# Specific Heat Capacity

- **Specific heat** is the amount of heat needed to raise 1 gram of a substance by one degree.
- Specific heat is given by the symbol  $C_p$ , or just  $C$ .
- Specific heat's **units** are usually:
  - $J/g^{\circ}C$
  - $cal/g^{\circ}C$

# Heat Capacity

- Objects with low heat capacities gain AND lose heat faster than those with high heat capacities.
- Water has a relatively high heat capacity. That's why it takes so long to boil water.

# Heating/Cooling Curve for Water





# Temperature Changes

- On Steps 1, 3, and 5 of the diagram temperature changes but phase doesn't.
- $\Delta H = m \cdot C_p \cdot \Delta T$ 
  - $\Delta H$  – change in enthalpy/heat (sometimes listed as **q**)
  - $m$  – mass (in grams)
  - $C$  – specific heat
  - $\Delta T$  – change in temperature (Celsius or Kelvin)
    - $\Delta T = (\text{Final Temp} - \text{Starting Temp})$
- Typically, this equation provides answers in J.

# Phase Changes

- On steps 2 and 4 of the diagram, Temperature doesn't change, so chemists needed another way to calculate enthalpy change that doesn't partially depend on temperature.
- Heat involved in these phase changes is called latent heat.

## Phase Changes *cont.*

- **Molar Heat of Fusion** ( $\Delta H_{\text{fus}}$ ) is the energy that must be absorbed to convert one mole of solid to liquid at melting point.
- **Molar Heat of Solidification** ( $\Delta H_{\text{solid}}$ ) is the energy that must be removed to convert one mole of liquid to solid at freezing point.
- $\Delta H_{\text{fus}} = -\Delta H_{\text{solid}}$

## Phase Changes *cont.*

- **Molar Heat of Vaporization** ( $\Delta H_{\text{vap}}$ ) is the energy that must be absorbed to convert one mole of liquid to gas at boiling point.
- **Molar Heat of Condensation** ( $\Delta H_{\text{cond}}$ ) is the energy that must be removed to convert one mole of gas to liquid at condensation point.
- $\Delta H_{\text{vap}} = -\Delta H_{\text{cond}}$

## Phase Changes *cont.*

- To calculate  $q$  or  $\Delta H$  during phase changes:
- $\Delta H = \text{mol} \cdot (\Delta H_{\text{fus}}$  or  $\Delta H_{\text{vap}})$ 
  - $\Delta H$  – change in energy
  - mol – moles of substance
  - $\Delta H_{\text{phase change}}$ 
    - Can use  $\Delta H_{\text{fus}}$  or  $\Delta H_{\text{solid}}$
    - Can use  $\Delta H_{\text{vap}}$  or  $\Delta H_{\text{cond}}$
- Typically, this equation provides answers in kJ.

# Formula Summary

- Enthalpy Change (no phase change)
  - $\Delta H = m \cdot C \cdot \Delta T$
- Enthalpy Change (phase change)
  - $\Delta H = \text{mol} \cdot \Delta H_{\text{phase change}}$

# Thermochemical Equations

- Because you've now seen that many equations or interactions involve changes of heat, chemists need a way to include these details in your reactions.
- A **thermochemical equation** is a balanced chemical equation that includes the enthalpy change.

# Thermochemical Equations



- This reaction releases 890 kJ of heat, and so it can be written one of two ways...
- $\text{CH}_4 (\text{g}) + 2\text{O}_2 (\text{g}) \rightarrow \text{CO}_2 (\text{g}) + 2\text{H}_2\text{O} (\text{l}) \quad \Delta H = -890 \text{ kJ}$
- OR
- $\text{CH}_4 (\text{g}) + 2\text{O}_2 (\text{g}) \rightarrow \text{CO}_2 (\text{g}) + 2\text{H}_2\text{O} (\text{l}) + 890 \text{ kJ}$

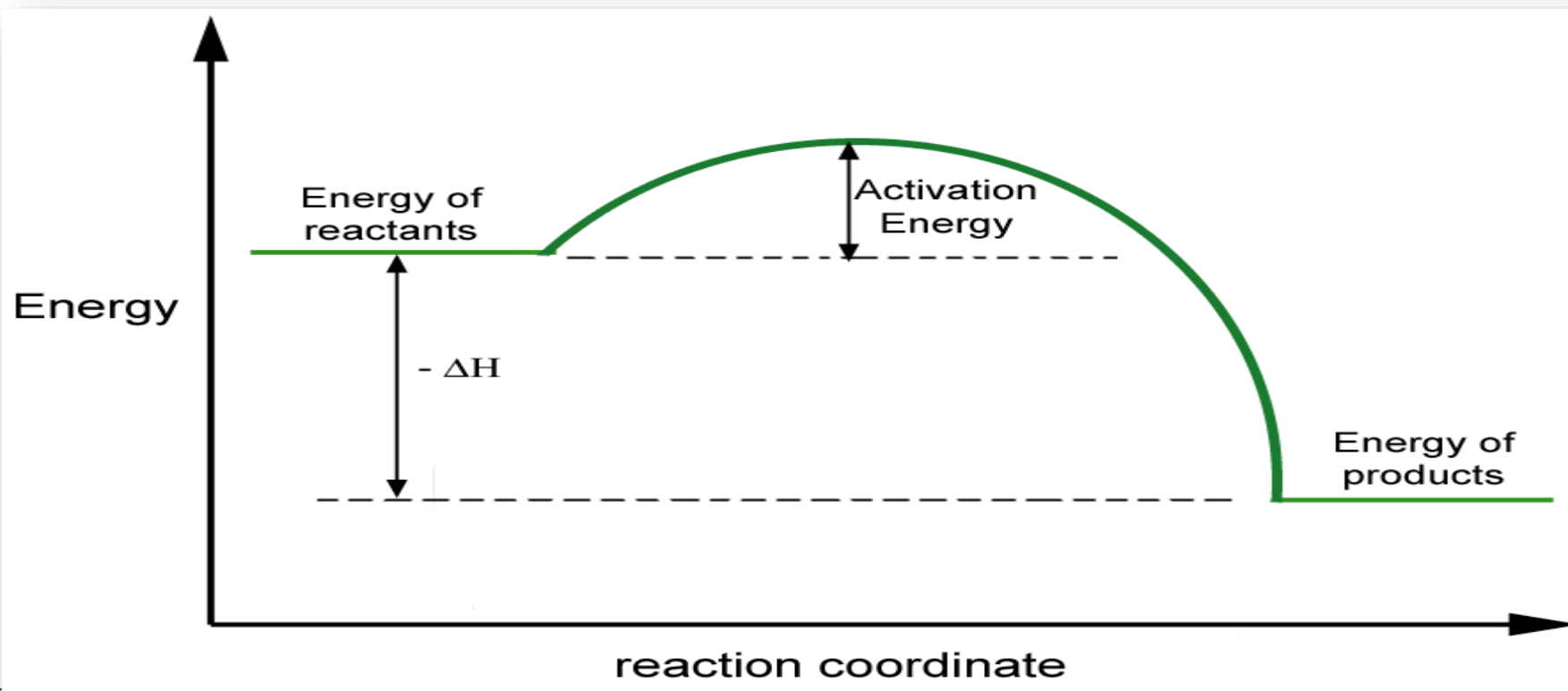


# Thermochemical Equations

- In **exothermic** reactions, heat is given off ( $-\Delta H$ ) and is thus listed on the **product** side.

# Exothermic Energy Diagram

- Energy is released during the reaction and the surroundings get warmer.

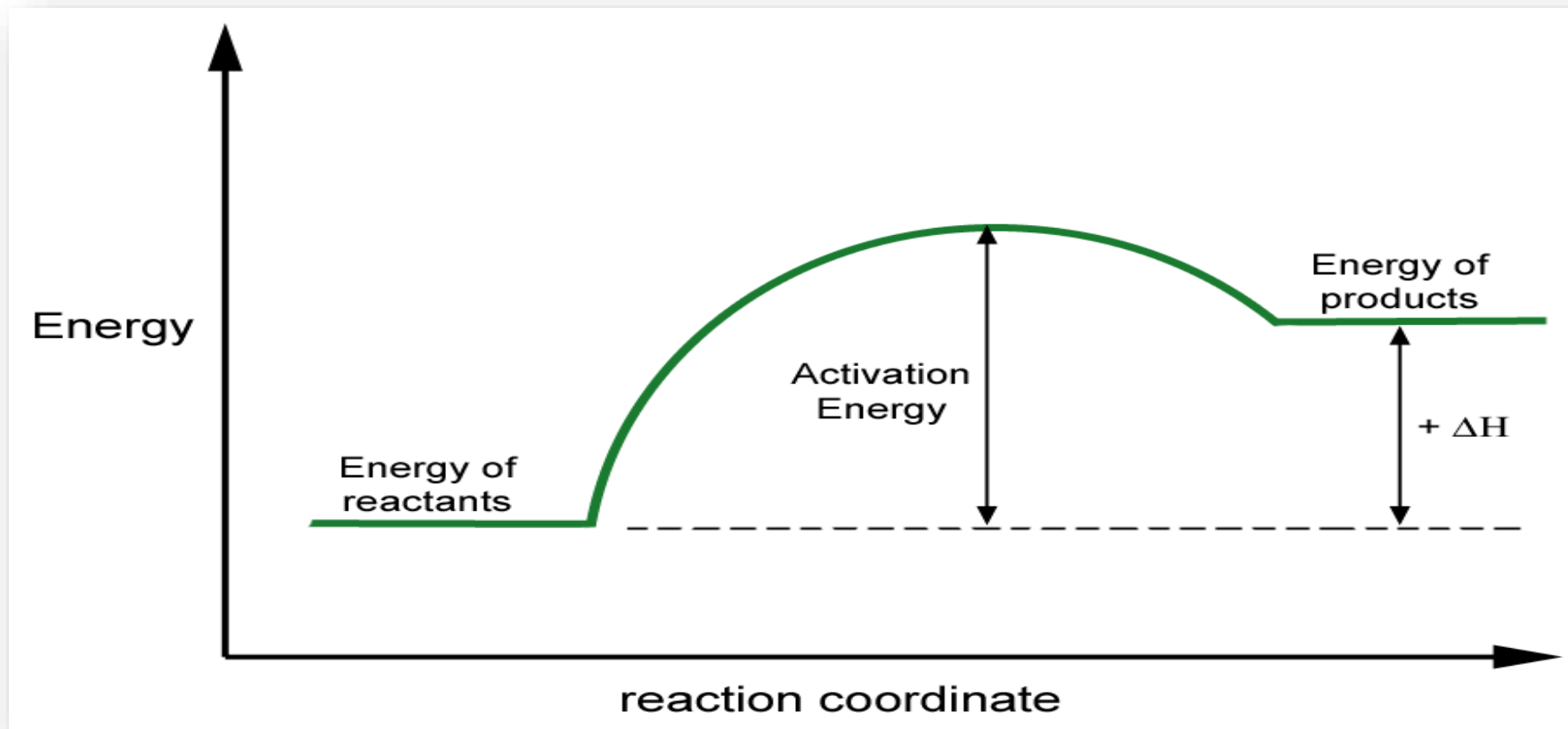


# Thermochemical Equations

- In **endothermic** reactions, heat is absorbed ( $+\Delta H$ ) and is thus listed on the **reactant** side.

# Endothermic Energy Diagram

- Energy is absorbed during the reaction and the surroundings get cooler.



# Thermochemical Equation Practice

- Sodium bicarbonate decomposes:



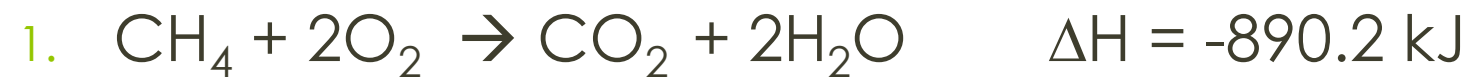
- How much heat (in kJ) is needed to decompose 2.24 moles of sodium bicarbonate?

# Thermochemical Equation Practice

When carbon disulfide is formed from its elements, 89.3 kJ heat is absorbed.

- Write the reaction.
- Is the reaction endothermic or exothermic?
- Calculate the amount of heat in kJ that is absorbed when 5.66 g of carbon disulfide is formed.

## Additional Examples



How much heat is released when 25 g of  $\text{CH}_4$  reacts with excess  $\text{O}_2$ ?

## Additional Examples



How much heat is released when 0.75 mol of CO reacts with excess  $\text{O}_2$ ?



## Additional Examples



How many grams of  $\text{SO}_3$  react when 575 kJ of heat is absorbed?

## Additional Examples



How many kilojoules of heat are produced when 3.40 mol of iron(III) oxide reacts with an excess of carbon monoxide?

# Hess's Law

- Provides a way to calculate the heat of the reaction when it cannot be measured directly.
- Hess's law of heat summation states that if you add two or more thermochemical equations to give a final equation, then you can also add the heats of the reaction to give the final heat of reaction.

# Hess's Law

- **Reasons to use this law:**

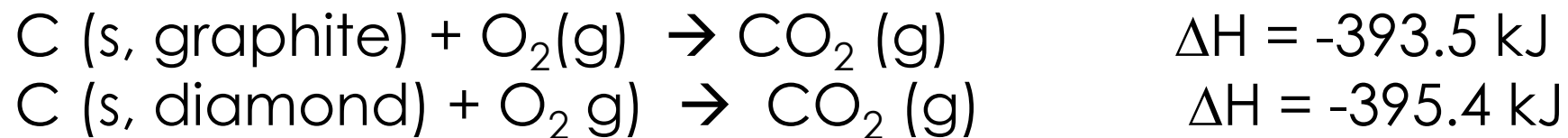
1. The reaction is too slow to measure the heat of reaction.
2. The reaction is an intermediate step.
3. You might not want to destroy material undergoing the reaction.

# Hess's Law Practice 1

Graphite is more stable than diamond so in time...



Use the following known thermochemical equations to calculate the heat of reaction for the above equation:



## Hess's Law Practice 2

Calculate the enthalpy change for the formation of carbon dioxide from its elements.



Use the following thermochemical equations:



## Hess's Law Practice 3

What is the enthalpy change for the following reaction?



Use the following thermochemical equations:

